WINE

by MAYNARD A. AMERINE

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This happy invention of man is a solution of hundreds of subtly interacting substances. Modern understanding of the wine-making process cannot explain a great wine but guarantees a good one

by Maynard A. Amerine

Wine is a chemical symphony composed of ethyl alcohol, several other alcohols, sugars, other carbohydrates, polyphenols, aldehydes, ketones, enzymes, pigments, at least half a dozen vitamins, 15 to 20 minerals, more than 22 organic acids and other grace notes that have not yet been identified. The number of possible permutations and combinations of these ingredients is enormous, and so, of course, are the varieties and qualities of wines. Considering the complexity of the subject, it is not surprising that perhaps more nonsense has been written about the making, uses and appreciation of wine than about any other product of man or nature.

Nevertheless, it can be said that in the 20th century wine making has become a reasonably well-understood art. The chemical processes involved are now sufficiently known so that the production of a sound wine is no longer an accident (although the production of a great wine may still be). For this we are indebted primarily to Louis Pasteur, who founded the modern technology of wine making along with several branches of chemistry, microbiology and medicine. Pasteur put the making of wine (and of beer as well) on a rational basis by explaining fermentation, which for thousands of years had been an unsolved mystery.

It seems likely that man's discovery of wine came later than that of beer (a fermentation product of grain) or of mead (a fermentation product of honey), because grapes grow only in certain climates and environments. By Neolithic times, however, the peoples of the Middle East were well acquainted with the fermented juice of the grape, and one of the oldest inscriptions in Egypt (on the tomb of Ptahhotep, who lived about 2500 B.C.) depicts the making of wine. The "blood of the grape" attracted ancient man not only as a beverage but also as a medicine and a symbolic offering to the gods.

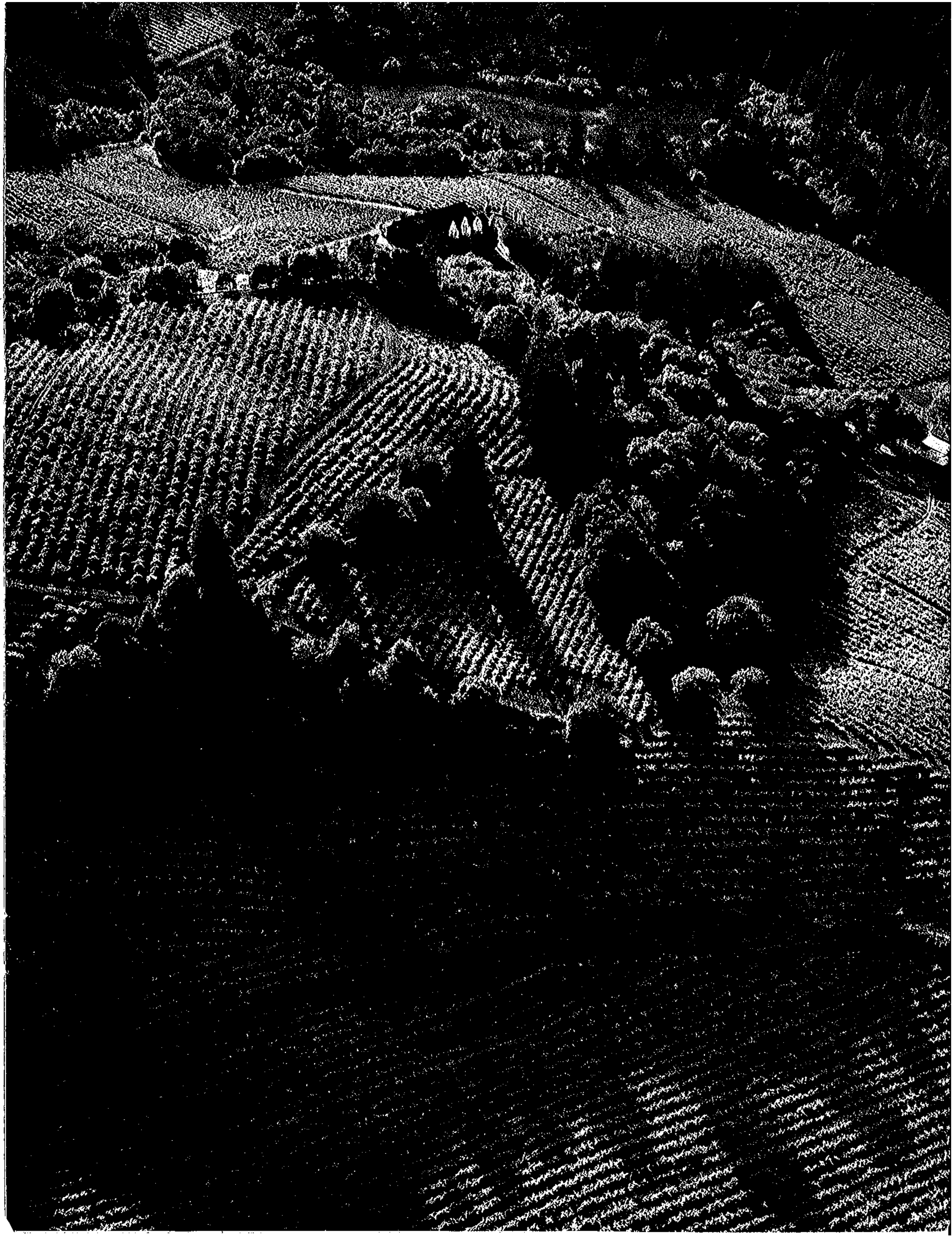
The grape is its own wine maker. One simply pressed out the juice, let it stand, and its sugars turned into alcohol. Not until the 19th century did chemists begin to unravel the nature of this process. In 1810 Joseph Louis Gay-Lussac made the first crucial contribution toward solution of the mystery by discovering the general chemical formula of the breakdown of sugar into alcohol and carbon dioxide: $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$. Plainly this change did not take place spontaneously. What caused the sugar to break down? Gay-Lussac conjectured from his experiments that the process was stimulated somehow by oxygen. The German chemist Justus von Liebig put forward another hypothesis: that the fermentation arose from the "vibrations" of a decomposing "albuminoid" substance. Liebig's authority was so powerful that his view was not seriously challenged until the young Pasteur embarked on his studies of fermentation in the 1850's.

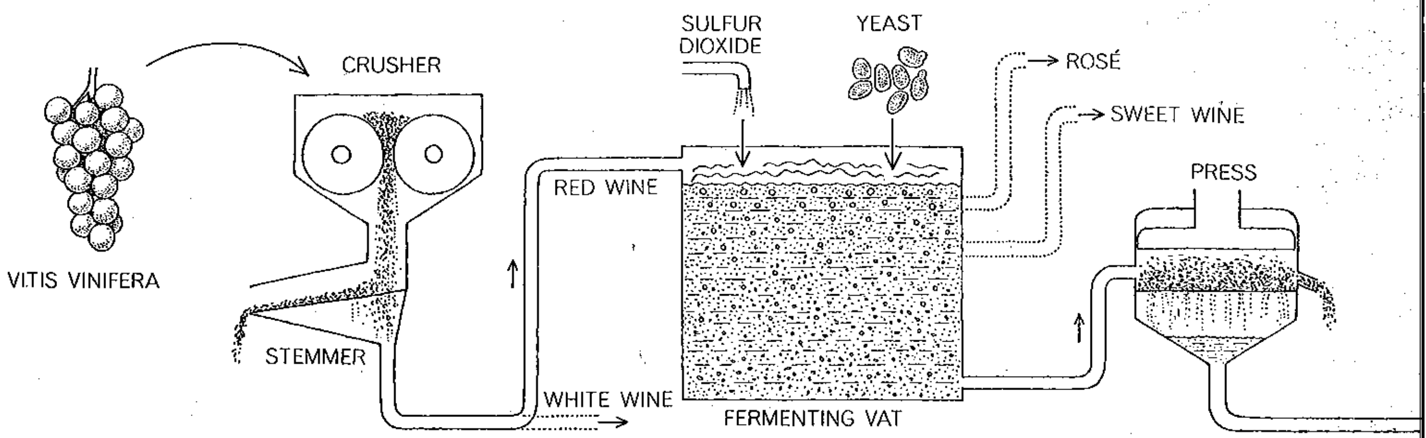
The Role of Yeast

"How account," Pasteur asked, "for the working of the vintage in the vat?" With his gift for designing experiments that went to the heart of the matter, Pasteur soon demonstrated that the working was produced by the microscopic organisms known as yeast. "Fermentation," he concluded, "is correlative with life." He showed that an infusion of yeast would convert even a simple sugar solution into alcohol, and he went on to identify some of the factors, such as acidity or alkalinity, that controlled the metabolic activities of the yeast organisms and thus determined the properties of a wine. Pasteur announced his main discoveries in two historic papers: *Mémoire sur la fermentation appelée lactique* (published in 1857) and *Études sur le vin* (1866).

How does the grape acquire its yeast? As every gardener knows, the skin of growing grapes is covered with a delicate natural bloom. It consists of a waxy film that collects cells of molds and wild yeasts, which are deposited on the grape by agencies such as the wind and insects. The skin of a single grape may bear as many as 10 million yeast cells. Of these, 100,000 or more are cells of the varieties called wine yeasts, of which the principal one is *Saccharomyces cerevisiae* var. *ellipsoideus*. It is the enzymes of the wine yeasts that are responsible for the fermentation of the grape's sugars to alcohol and for the creation of the numerous by-products that partially account for the flavor and other properties of the wine. The nature of the activity of the yeasts importantly affects the wine's quality, consequently it is one of the factors modern wineries are careful to control. In some old European vineyards the grapes and yeasts seem to have established over the centuries a natural harmony that brings out the grapes' best qualities in the wine. But most wineries, even in Europe, now improve on nature by adding pure cultures of desirable yeasts and using chemicals to sup-

CALIFORNIA VINEYARDS cover the hills surrounding the Napa Valley. Varieties of *Vitis vinifera*, the species of grape from which most European wines are made, adapt readily to the warm California environment.





WESTERN U.S. METHOD of producing red wine duplicates the European process. The grapes are crushed between rollers (*left*), forming an intermediate product known as "must." The must is piped to a fermenting vat where yeasts speed the transformation

press the growth of undesirable yeasts present on the grape skins.

The Effect of Climate

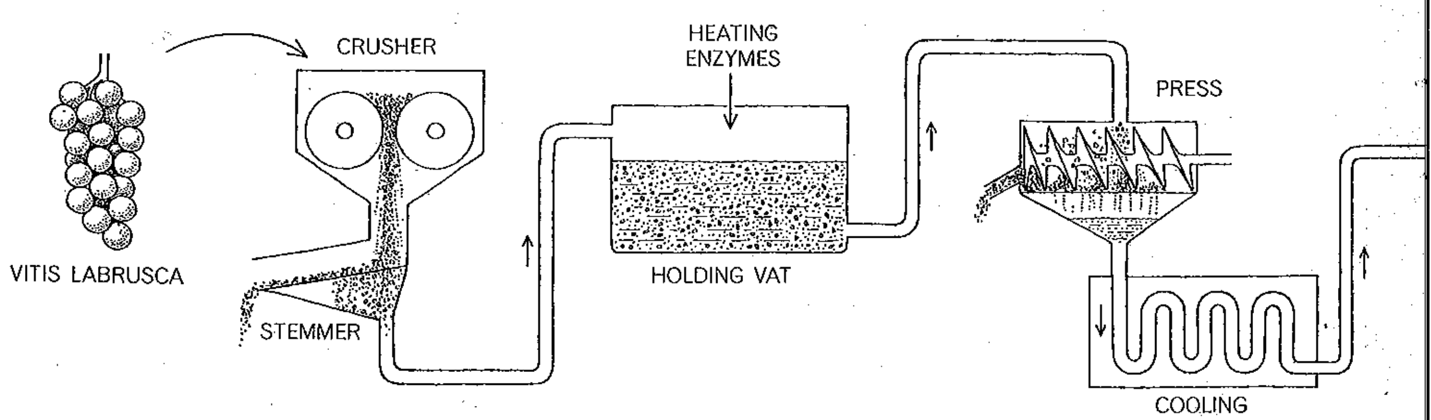
The making of a wine starts long before the grapes reach the winery—indeed, long before the grapes are harvested from the vine. The grape is a complex product of soil, water, sun and temperature. Of these factors, the most significant single one is temperature. Grapes will grow only within the belts of the Northern and Southern hemispheres where the average annual temperature is between 50 and 68 degrees Fahrenheit [*see lower illustration on page 11*]. Even in these regions the European grape *Vitis vinifera* does not survive in areas marked by certain unfavorable conditions: summer temperatures not warm enough to ripen the fruit (as in most of Britain), high summer humidity that excessively exposes it to mold diseases or insect predators (as in the southeastern U.S.) or late spring frosts (as in the northwestern U.S.).

The ideal climate for wine grapes is one that is warm but not too warm, cool but not too cool. On the one hand, a long growing season is required so that the grapes will produce a high content of sugar for conversion into alcohol. On the other hand, comparatively cool temperatures are desirable because they produce grapes with high acidity, an important contributor to the quality of wine, particularly the dry table wines. Both of these climatic conditions are well fulfilled in areas such as the Bordeaux district of France, northern Spain, central and northern Italy, Yugoslavia and northern California—and those areas produce fine red table wines. In areas with cooler or shorter growing seasons, such as Germany, Switzerland, Austria, the eastern U.S. and even the Burgundy district of France, the grapes in some years do not develop enough sugar, and sugar must be added when they are brought to the winery. This addition cannot, however, replace flavor components that are missing when the grapes have not ripened fully. The variability of the summer climate in Europe is the main reason for the fluctuation in the quality of its wines from year to year and for the emphasis on vintage years.

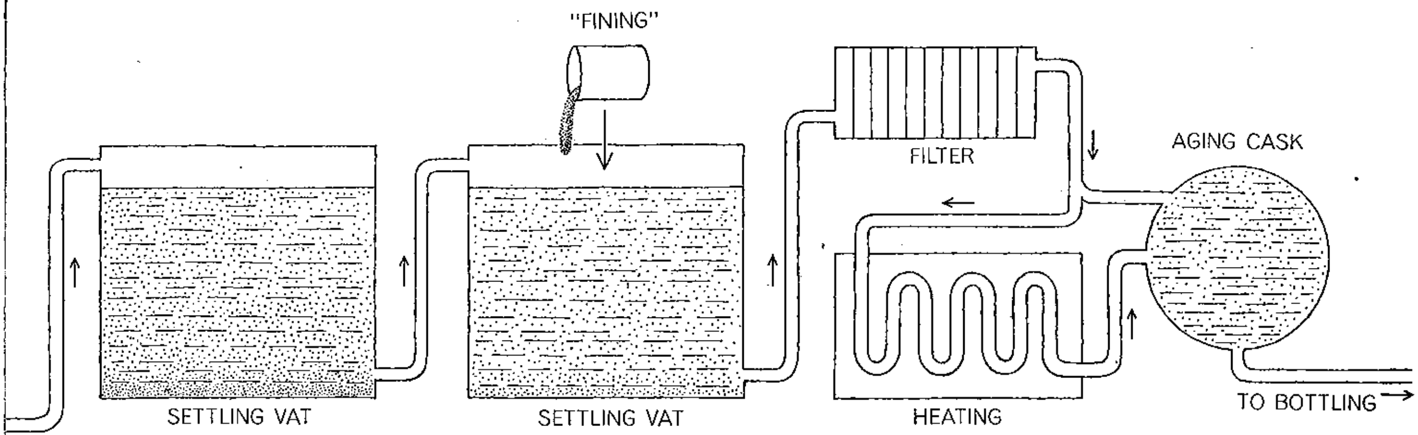
Although a warm climate (such as that of southern Spain, Sicily, Cyprus and southern California) produces grapes with a high sugar content, they have the handicap of comparatively low acidity. These grapes are suitable for the sweet dessert wines, but they lack the subtle flavors and color of grapes grown in cooler areas. Moreover, they are sometimes overripe when they come to the fermenting vats, with sad effects on quality if one attempts to produce a table wine from them.

The Grape

No less important than the characteristics of the climate are the char-



EASTERN U.S. METHOD of producing red wine begins with the crushing (*left*) of *Vitis labrusca* grape, a species low in sugar. Must is piped into a holding vat, where enzymes are added to break down mucilaginous substances in and around the pulp. The desired color



of sugars into alcohol, and then to a press where skin and seeds are separated out. The juice proceeds through two settling vats, wherein the "fining" process removes impurities. It is filtered, sometimes heated and cooled, and aged in casks prior to bottling.

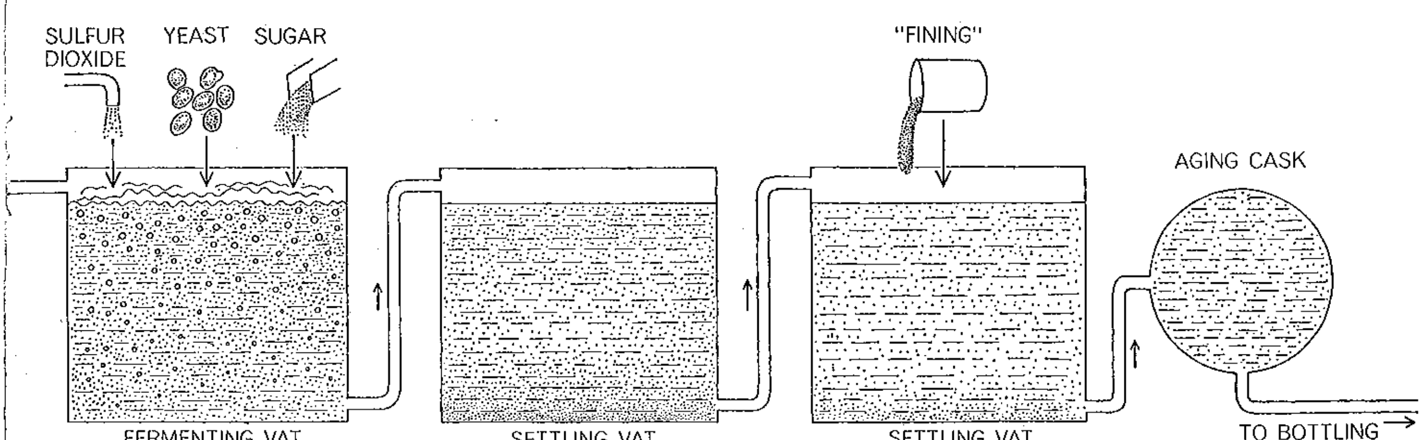
acteristics of the grape. One of the benign aspects of the grape plant—which holds much promise for future wines—is its great variability. One species alone, *Vitis vinifera,* has some 5,000 known varieties, and even the less popular species are available in about 2,000 varieties. Grape breeders have also produced many hybrids between the species. The grape varieties differ in color (white, green, pink, red or purple), in the size of the grape clusters, in the texture of the grape (firm and pulpy or soft and liquid), in sugar content, in acidity, in earliness or lateness of ripening and in susceptibility to insects and diseases. With this variability in the material, plant geneticists look forward to breeding new varieties of grapes that will be tailored to specific climates, to the types of wine and to new heights of taste, aroma and bouquet. (As wine experts define the terms, aroma refers to the fragrance of the grape; bouquet, to the fragrance imparted by fermentation and aging.)

Vitis vinifera is by far the preponderant species of wine grape grown in vineyards throughout the world. The plant is believed to have originated near the shores of the Caspian Sea in what is now, the southern U.S.S.R. From there early travelers and traders spread it around the Mediterranean, then to northern Europe and eventually explorers transported it to continents overseas. (More than 81 percent of the world's vineyard acreage and wine production are still concentrated, however, in Europe and North Africa, with France the leader.) In the U.S. the *vinifera* species has found a hospitable home in California, and some 100 varieties of this species are cultivated commercially there. *Vinifera* is vulnerable to the diseases and insects that thrive in a hot and humid summer climate; for this reason many vineyards in the eastern U.S., Canada, Brazil and certain areas in Europe cultivate other species, such as *Vitis labrusca* or *Vitis rotundifolia.*

Now let us examine the wine-making process. To follow it in detail we shall consider the typical procedure in a modern California winery.

The Wine-making Process

To begin, let us analyze the raw material. In a mature grape about 10 to 20 percent of the material by weight is accounted for by the skin, stem and seeds, and the remaining 80 to 90 percent is pulp and juice. The pulp and juice, when piped into the fermenting vat, is called "must." Chemically the grape must is mostly water, but between 18 and 25 percent by weight is sugar (the amount varying with the variety and ripeness of the grape). The sugar consists mainly of dextrose (that is, glucose that rotates polarized light to the right) and levulose (or fructose, which rotates polarized light to the left). The grapes from which table wines are made usually contain dextrose and levulose in about equal



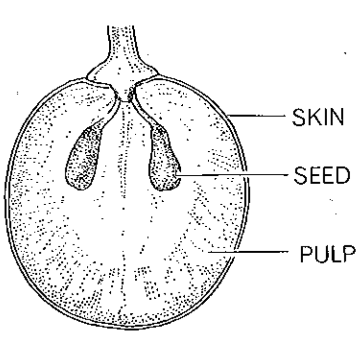
is attained by heating. Must proceeds to a fermenting vat where sugar as well as yeast and sulfur dioxide are added. Removal of impurities by fining takes place in settling vats, and the wine is then aged. Some Eastern wines are pasteurized before bottling.

amounts; for sweet wines vintners would prefer grapes with a higher proportion of levulose, because it is nearly twice as sweet as dextrose. In addition to these two principal sugars, grapes also contain small quantities of other carbohydrates, such as sucrose, pentoses and pentosans.

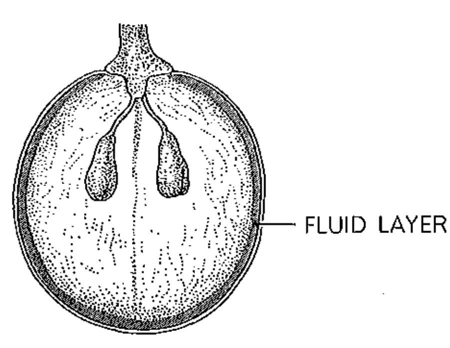
Acids make up between .3 and 1.5 percent of the grape must by weight. The two principal acids again are optically opposite forms: dextrorotatory tartaric acid and levorotatory malic acid. There are also small amounts of other acids: citric, oxalic, glucuronic, gluconic and phosphoric. The *p*H, or active acidity, of mature *Vitis vinifera* grapes in California runs between 3.1 and 3.9.

Among the many other substances that have been identified in analyses of grape must are 20 amino acids (found in the free state as well as in proteins), 13 anthocyanins (the pigments of many colored flowers), other pigments, tannins, odoriferous compounds and the various vitamins, enzymes, minerals and other ingredients already mentioned. Obviously many of these substances contribute to the making of wine by providing nutrient for the fermenting yeasts. The contributions of individual ingredients to the quality of wine, however, are imperfectly understood; presumably no one will ever be able to write a formula for a perfect wine, because personal taste is an indispensable part of the equation.

DELICATE BLOOM of grape skin consists of a waxy film that collects molds and yeasts. A single grape may accumulate 100,000 yeast cells with enzymes responsible for fermentation. Where the waxy film has been brushed off several grapes (*center*) a bright shine results.



CABERNET FRANC, shown here in cross section, is an Old World grape of relatively low acidity that flourishes in California.



CONCORD GRAPE of the northeastern U.S. has a mucilaginous layer separating skin and pulp, hence its "slip skin" classification.

The fermentation process is enormously complicated [*see illustration on page* 9]. The breakdown of glucose alone involves no fewer than 22 enzymes, six or more coenzymes and magnesium and potassium ions. A number of other sequences, including the well-known Krebs cycle, participate in the process. From these many reactions emerges a mixed collection of other products in addition to alcohol, among them acetaldehyde, glycerol, succinic acid, esters and other aromatic compounds. The problem of the wine maker is to control the production and accumulation of this multitude of diverse products. In a modern winery this is done by various chemical and physical means.

Grapes have to be taken from the vine to the winery as quickly and carefully as possible in order to minimize their loss of water and sugar after picking and to prevent spoilage. At the winery they are immediately put in a crusher, which crushes the skins, freeing the pulp and juice (without breaking the seeds), and removes the stems. In the case of a white wine the juice is pressed out at this point and sent alone to the fermenting vat. For the making of red wine the entire contents of the crusher—juice, pulp, skins and seeds—go into the fermentation process. The red wine will take its color from the pigment in the skins and its strong flavor and astringency from tannins and other substances in the skin and seeds. (The rosé wines that have become more popular in recent years are made by starting the fermentation with the skin and pulp present, then, after about 24 hours, pressing out the juice and letting it complete the process alone.)

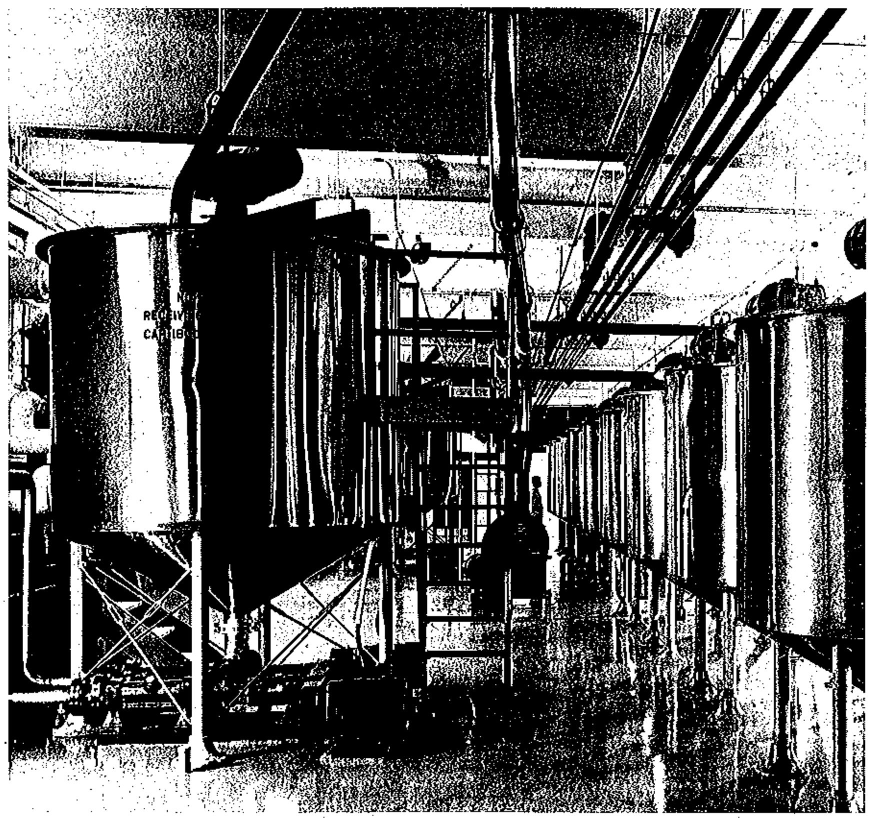
Wine in the Vat

In the fermenting vat (in California it is usually constructed either of red-

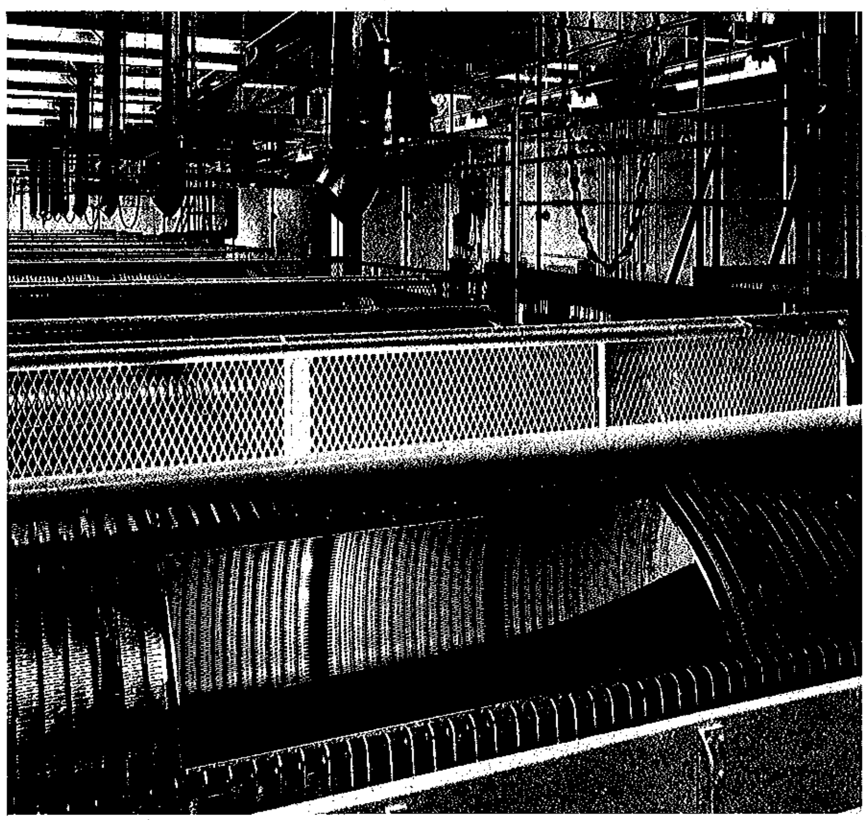
wood or of concrete) the first step is treatment of the must with liquefied sulfur dioxide or a sulfurous acid or salt. The main function of this chemical is to inhibit the growth of the wild yeasts on the grape skins. They are replaced by the addition of pure cultures of yeasts that will produce a better wine. Besides suppressing the deleterious yeasts the sulfur dioxide reduces oxidation (which may have a baneful effect, particularly on the quality of white wines) and also helps to acidify and clarify the wine. Sulfur dioxide is a dangerous tool—an excess of it will ruin the wine—but all in all its use has been a major 20th-century benefit to wine making, contributing in various ways to better regulation of the fermentation, a higher yield of alcohol from the sugar and a more flavorful product. When sulfur dioxide is used, the natural yeast flora from the grape are largely inhibited and an actively fermenting culture of yeast must be added.

Another recent innovation is careful control of temperature in the fermenting vat. Cooling systems are used to carry off the heat produced by fermentation so that the temperature in the vat is kept below 85 degrees F. (for red table wines) or below 60 degrees (for white wines). The slow fermentation at low temperatures produces more esters and other aromatic compounds, a higher yield of alcohol and a wine that is easier to clear and that is less susceptible to bacterial infection. In the opinion of most enologists it results in a better bouquet and aroma. The duration of the fermentation in a modern winery varies from a few days to a few weeks, depending on the temperature, the type of yeast used, the sugar content of the grapes and the kind of wine to be produced.

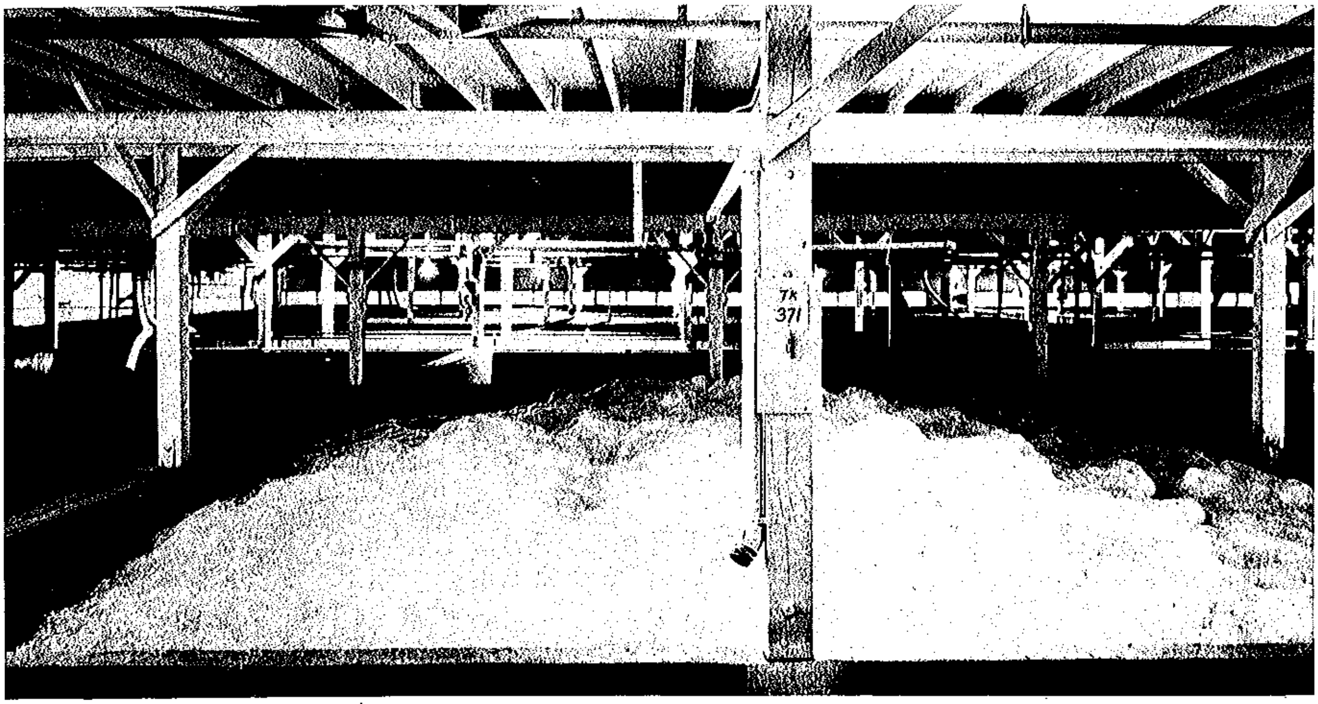
All wine is divided into two general classes, defined by the alcohol content. The table wines (also called "dinner," "dry" or "light" wines) contain not more than 14 percent of alcohol by volume. The "aperitif" and "dessert" wines (sherry, port, muscatel and the like) have a higher content, usually about 20 percent. They are given this high alcohol content by the addition of brandy distilled from wine. Added during the fermentation, the brandy stops the action of the yeast, and the wine is then left with some of its sugar unconverted to alcohol. In the making of muscatel, for example, the brandy is added and the fermentation halted when the juice still contains 10 to 15 percent of grape



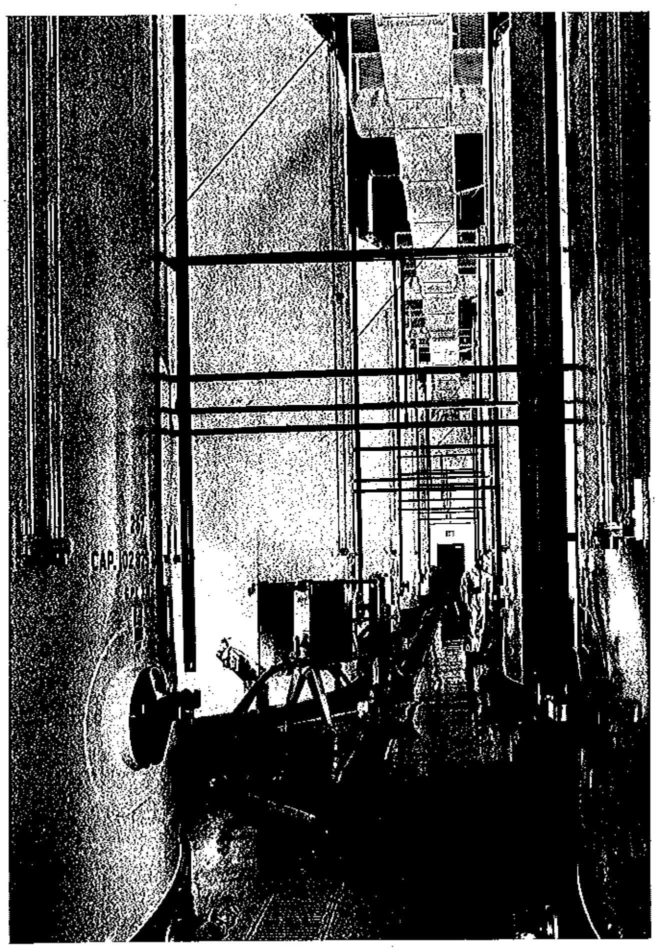
RECEIVING TANKS at left transfer must from a crusher on the floor above to the holding vats at right, enabling the winery to process the harvest of two types of grape. This photograph and the one below were made at the Taylor Winery in Hammondsport, N.Y.



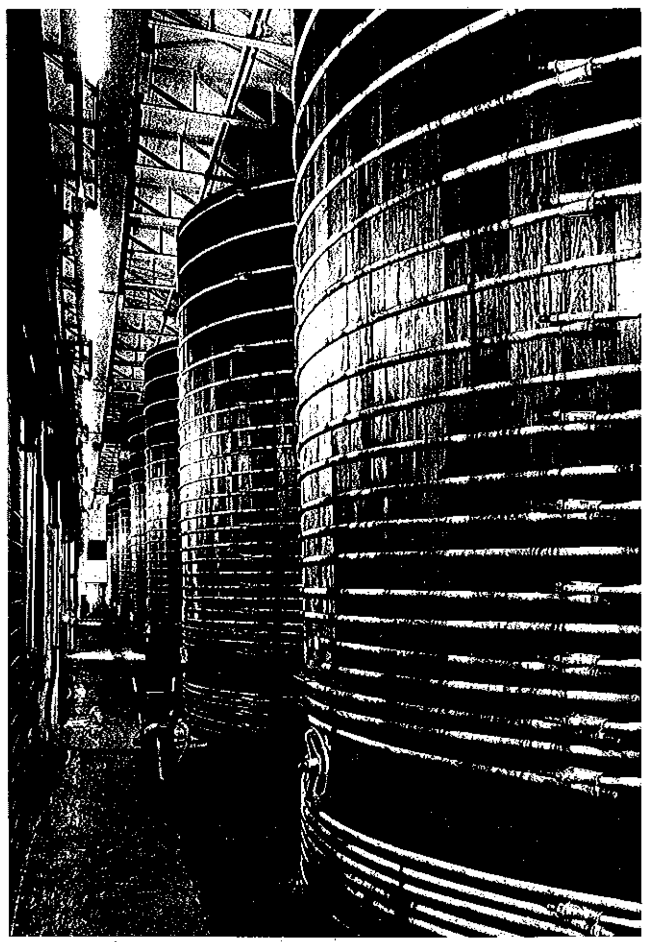
PRESSES receive crushed grapes from holding vats on the floor above through pipes (*top*). The black rubber bag visible inside the press in the foreground will be inflated with air, forcing residual skins and seeds to cling to the sides of the stainless steel cylinder.



"STORMY" STAGE of fermentation is under way in this vat at the United Vintners winery in Asti, Calif. Approximately 36 hours after yeast is added the temperature of the juice rises as high as 85 degrees and carbon dioxide bubbles violently to the surface.



FERMENTING TANKS shown here can hold 100,000 gallons. They are made of concrete with a glass lining. The thin pipes between the tanks exchange heat to maintain a uniform temperature.



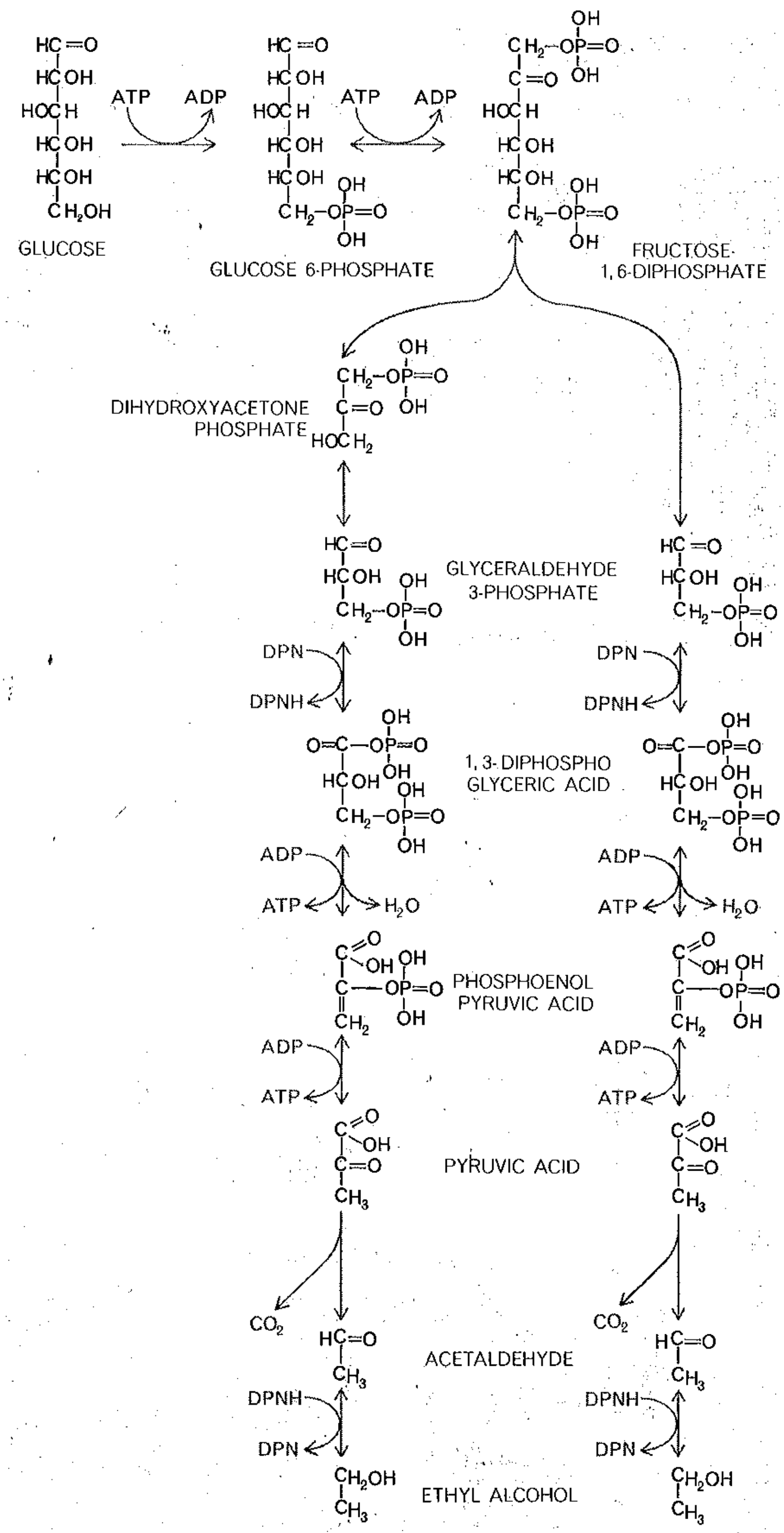
REDWOOD VATS house the aging wine and facilitate mellowing by admitting oxygen through redwood planks. These vats, photographed at the Taylor Winery, have a capacity of 63,000 gallons.

sugars by weight; the result is a very sweet wine. For port the fermentation is stopped a little later (at a sugar level of 9 to 14 percent) and for a dry sherry it may be allowed to proceed until the sugar content is 2.5 percent or less.

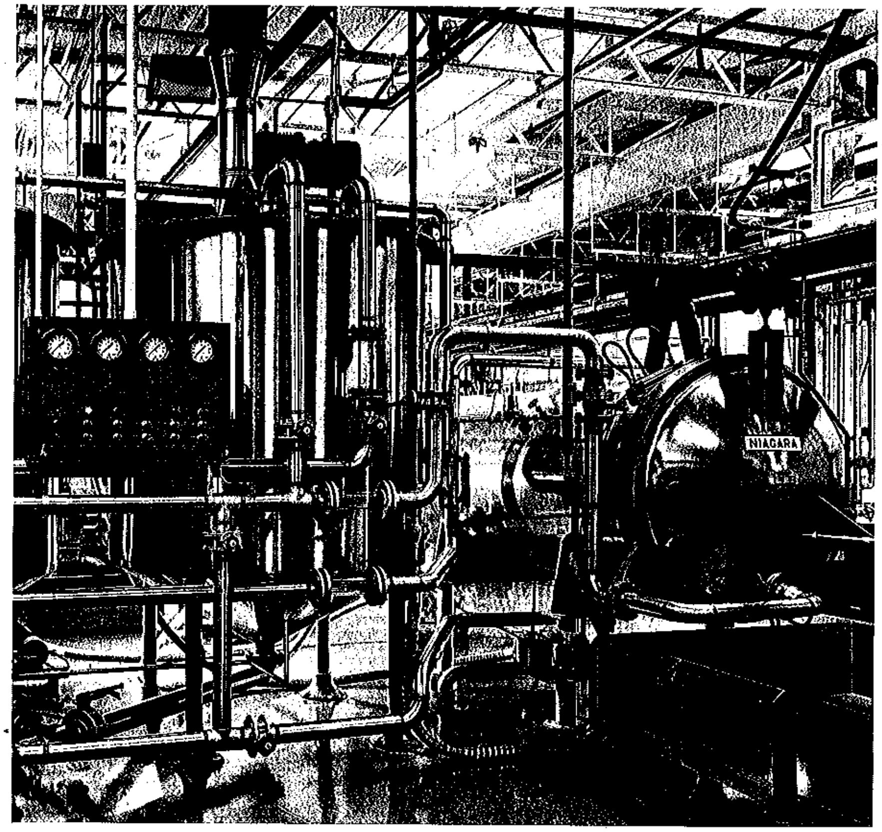
For the sake of simplicity let us proceed with the more typical case of a red table wine. When part of its sugar has been converted to alcohol and adequate color has been extracted from the skins, the partially fermented juice is separated from the pulp. At this time the skins are mainly free and floating on top; the liquid is drained off as "free run" and is considered to make the best wine. The rest of the juice is pressed out of the pulp by the familiar wine press (which most people confuse with the machine used to crush the grapes before they are put in the fermenting vat). The press used in many modern wineries still looks much as it has always looked—a hardwood container with a plunger—but nowadays a hydraulic ram replaces the old screw contrivance turned by hand. Recently developed cylindrical presses and roller presses are also in use.

The juice now proceeds to the completion of its fermentation and to the clearing and aging stages. Not to be guilty of omitting entirely from this account the important category of sparkling wines, I shall merely mention here that they are made from dry table wines by means of a secondary fermentation in a closed container, involving the addition of a calculated amount of sugar and 1 percent of a pure yeast culture. This fermentation produces the extra carbon dioxide—amounting to an internal pressure of four or five atmospheres in the bottle—that accounts for the fizz of champagne.

For clarification of the wine the fermented juice goes to settling vats. There the suspended yeast cells, cream of tartar and small particles of skin and pulp rapidly settle out of the liquid. Various chemical processes and a form of fermentation still continue, however. Wine, it has been said, is a living thing, and indeed in a sense it does go on growing and maturing—in the settling vats and later in its aging periods in cask and bottle. In the vats the yeast cells, as they break down, particularly in a wine juice of high acidity, stimulate the growth of *Lactobacillus* bacteria. Enzymes from these bacteria decarboxylate the wine's malic acid (that is, remove COOH groups) and convert it to lactic acid. This malo-lactic "fermentation," replacing a strong acid with



FERMENTATION entails the breakdown of the six-carbon sugar, glucose (*top left*) and the consequent production of alcohol. The splitting of the carbon backbone occurs when the intermediate product, fructose (*top right*), gives way to two molecules of glyceraldehyde phosphate. The major intermediate products are shown from top to bottom. The enzymes and coenzymes needed to power the process are represented by ATP and ADP, and DPN and DPNH. The reversible steps in the process are indicated by two-way arrows.



FILTERING UNIT shown at right in this photograph removes sediment from the wine in settling tanks (*left center*). Below the filter is a trough into which residue is dumped.

NEW BOTTLES containing domestic U.S. champagne are stacked on a "riddling" shelf of ash, counterpart of the French A-frame. Sediment accumulates in the neck and can be discarded by briefly uncorking the bottle. Both photographs were made at the Taylor Wineries.

a weak one, mellows the high-acid wine. Without it the high-quality wines of northern Europe could not be made.

As soon as possible the clearing wine is racked, or drawn off, from the settling lees to prevent excessive working and protect its flavor. The racking is repeated again and again, leaving behind lees at each step. During these off-pourings the wine also sheds the carbon dioxide with which it was charged in the fermentation process and absorbs oxygen from the air, which will help in its aging. To assist the clearing of the wine when racking alone does not suffice, wineries commonly inject "fining" substances (such as bentonite clay, gelatin, isinglass or egg white) that clump and precipitate the tiny particles in the wine; they may also apply pressure filtration, heat or chilling as aids to clearing.

Wine in Cask and Bottle

The aging of the wine begins in an oak cask. It is an extremely complex process of oxidation, reduction and esterification. The new wine gradually loses its yeasty flavor and harshness, declines in acidity and acquires a complex, delicate bouquet. As its pigments and tannin are oxidized, red wine turns a tawny color and white wine develops an amber hue. The amount of oxidation of its ingredients, by means of oxygen absorbed through the pores of the cask, is crucial to the eventual quality of the wine: the length of time it is left in the cask may make the difference between allowing a great wine to attain its potential and turning it into an ordinary one. If wine is bottled too soon, it may spoil or mature too slowly; if it is bottled too late, it will be vapid and off-color. The decision as to when to bottle is one of the most important in the wine maker's art. In present practice fine red table wines are kept in wooden cooperage for at least two years; white wines, from a few months to two years. Lesser-quality wines are stored in redwood, concrete or lined iron tanks.

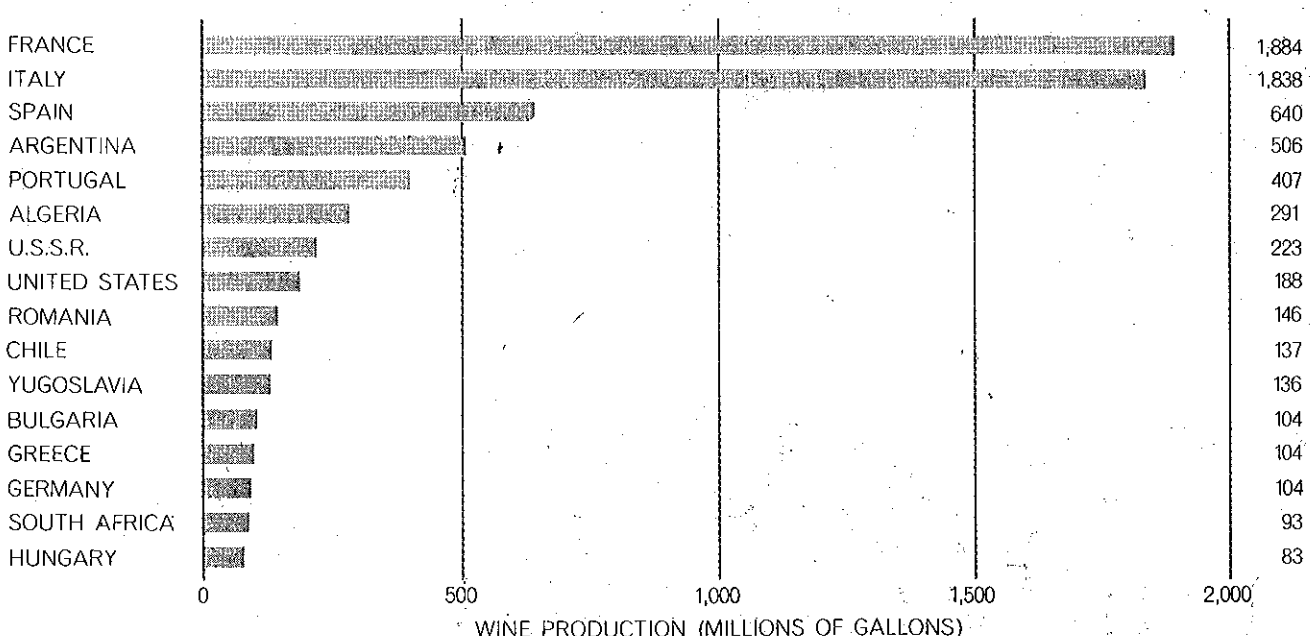
After bottling, wine does not cease to "work." Aging in the bottle serves to eliminate the aerated odor the wine acquired at the time of bottling, reduce the wine's content of free sulfur dioxide and improve its bouquet. It is a mistake, however, to suppose the older the wine, the better, or that a bottle encrusted with the grime of many years is likely to contain a wine of rare distinction. The contents may, in fact, have become worthless long ago. Only a few

very fine red wines benefit from prolonged aging. As a general rule, for a good red wine five to 10 years in the bottle is long enough, and a white wine will have reached its peak after two to five years. Wines of lesser quality require less time.

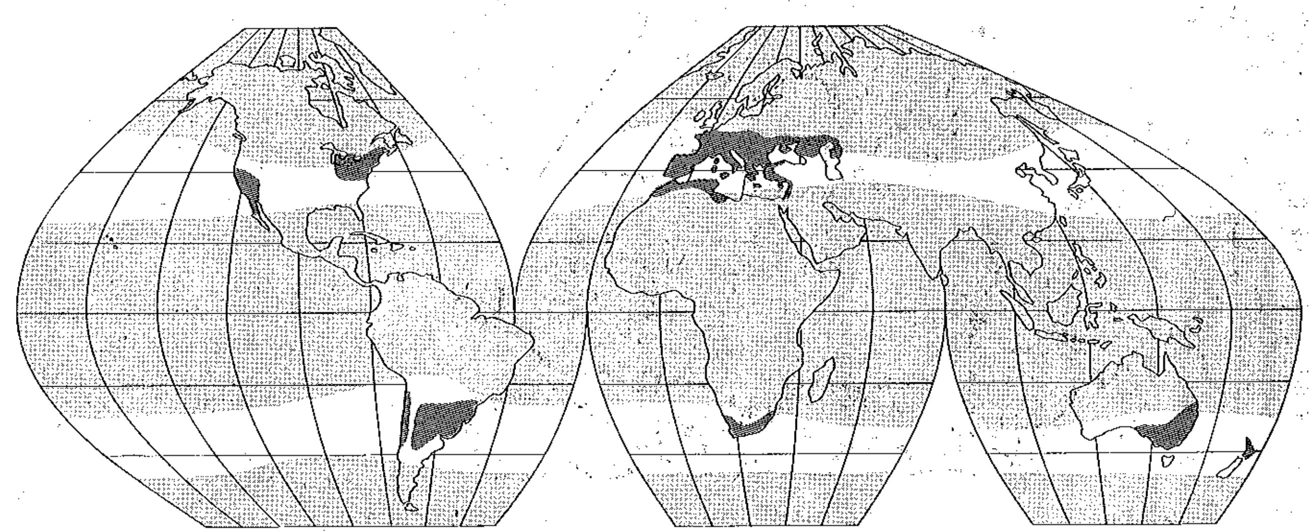
To summarize, the modern technology of wine making began with Pasteur's discovery that fermentation was produced by yeasts and that the process was far more complicated, with many more by-products, than Gay-Lussac's simple formula for the conversion of sugar to alcohol had suggested. The major modern developments have been the use of selected pure yeasts, the breeding and cultivation of superior varieties of grapes, the control of fermentation by certain chemicals and physical conditions (such as sulfur dioxide and cooling) and a gradual accumulation of more exact knowledge about the chemistry of the fermentation and aging processes. For all these advances, a truly great wine is still more or less a happy accident arising from time to time out of a particularly fortunate blend of the weather, the grape and the vintner's intuitive art. Much of the guesswork has been eliminated, however, from commercial wine making, and the quality of wines is a great deal more uniform than it used to be.

Even a brief account of wine making, which can touch only on the highlights, cannot pass over the fascinating subject of the consumption of the product. The wine maker and the wine consumer are themselves partners in a peculiarly intimate symbiosis; indeed, historically they used to be one and the same person! Modern enology sheds interesting light on some of the folklore of wine drinking.

The matching of wines to food (red wine with red meat, white wine with fish) cannot be defended, objectively speaking, as much more than a superstition. It is true that red wine shares with meat a complexity of taste and texture, and that the high acidity of white wine may add spice to the blandness of fresh fish and, in earlier times



LEADING PRODUCERS of wine are listed according to 1962 output in millions of gallons. The figures for Algeria, the U.S.S.R. and Chile are estimates. No statistics are available for China. France and Italy together produced about half of the world supply.



WINE-GROWING REGIONS of the world lie within belts where average annual temperature is between 50 and 68 degrees Fahrenheit. The hot summer of the southwestern U.S. and the humidity in the Southeast preclude the cultivation of *Vitis vinifera* grapes.

of nonrefrigeration, may have helped to mask the odor and taste of decaying fish. Most likely, however, the traditional ideas about food-wine pairing grew originally out of the simple geographical fact that a particular type of wine happened to be grown in a region that favored a particular food; that is, the coupling developed from agricultural rather than epicurean considerations.

The use of wine as medicine is another and much more interesting story. The medical historian Salvatore P. Lucia, of the University of California Medical School in San Francisco, asserts in his *A History of Wine as Therapy* that it is "the oldest of medicines." Salves made with wine were used in Sumer as early as the third millennium B.C., according to a clay tablet found in the ruins of Nippur. Virtually every culture has employed wine for medicinal purposes, either directly or as a solvent. It used to be listed in the U.S. *Pharmacopeia,* but it was dropped during prohibition (which all but killed the appreciation of wine in the U.S.) and has not been reinstated since. Many physicians, however, have resumed prescribing it for various ailments.

Wine is considered a specific for certain disorders because its alcohol is absorbed from the digestive tract into the bloodstream slowly (as opposed to the rapid absorption of pure ethyl alcohol) and because some of its ingredients may be metabolically helpful to the body. The physicians who believe in its therapeutic powers recommend it variously as an analgesic for minor pain, as a tranquilizer or sedative, as a vasodilator for hypertensive patients, as a diuretic, as a nutritional supplement for diabetics and as an aid to the absorption of fat by the intestines after an operation for ulcers or stomach cancer. The noted medical teacher William Dock, professor of medicine at the Downstate Medical Center of the State University of New York, has remarked: "It is useful to think what would happen if alcohol should be discovered all over again.... The sales for all other sedatives and tranquilizers would go down; there would be four-page spreads with color in all the medical journals...and the stock of the patent licensees would go right through the ceiling on Wall Street. The lucky discoverers would get every possible honor, as did the men who discovered insulin."

The Author

MAYNARD A. AMERINE is professor of enology at the University of California at Davis. Amerine was graduated from the University of California at Berkeley in 1932 and obtained a Ph.D. in plant physiology there in 1938. He joined the Davis faculty in 1936; from 1957 to 1962 he was chairman of the department of viticulture and enology at Davis. During World War II Amerine served with the Chemical Warfare Service of the U.S. Army in Algeria and India. He is a past president of the American Society of Enologists and the author of several books on wine making, including *Table Wines: The Technology of Their Production in California* (with M. A. Joslyn).

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